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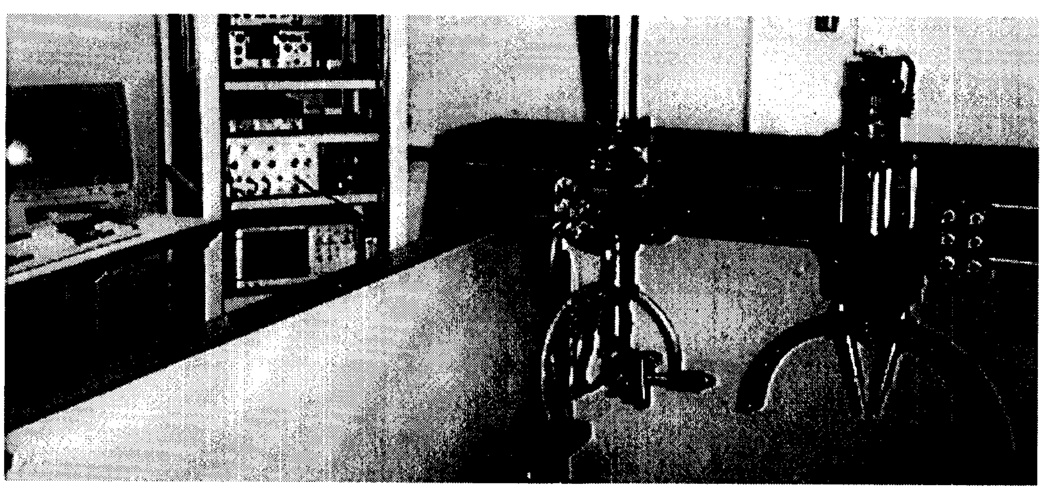
The following represent two in a series of topics representing the JPL's NDE activity of the NDEAA Group.

JPL NDEAA ACTIVITY - I - LLW NDE

NDE of Composite materials using Leaky Lamb Waves (Yoseph Bar-Cohen, JPL, 818-354-2610, yosi@jpl.nasa.gov, http://ndeaa.jpl.nasa.gov/)

Composite materials are now making a significant percentage of flaw critical structures, such as aircraft and spacecraft. Added to the concern regarding NDE of these materials during production and assembly, composites are now reaching service duration for which the issue of aging is also requiring attention. The key to efficient inspection of composites is the ability to determine their integrity and serviceability. Standard NDE methods, which were developed to inspect metallic structures, were adapted by the industry for inspection of composites partially accounting for the multi-layered anisotropic nature of these materials. The adapted NDE methods provide limited and mostly qualitative information about the material properties and defects. The JPL's NDEAA Group Leader discoveries of the ultrasonic Polar Back-Scattering (PBS) and the leaky Lamb wave (LLW) phenomena (1979 and 1982, respectively) in composites added a powerful arsenal of quantitative NDE methods. These phenomena are based on obliquely insonified ultrasonic waves and numerous analytical and experimental studies followed the discovery of these phenomena. These studies, particularly of the LLW phenomenon, enabled the quantitative NDE of the elastic properties and the ability to uniquely characterize flaws, as well as evaluating the quality of adhesive bonded-joints. The development of theoretical analysis has done cooperatively with Prof. Ajit Mal of UCLA since 1987. The data is acquired in the form of dispersion curves that show the LLW phase velocity as a function of the frequency along various polar angles with the composite material fibers. To harness the capability that the LLW and PBS offer for NDE a unique scanner was developed by JPL jointly with QMI. The scanner was developed as a C-scan attachment that is computer controlled. A view of the JPL scanner is show in Figure 1, where the arch plane represents the polar angle of the acquired dispersion curve. The height of the transducer pair as well as the pitch-catch and polar angles are all controlled at high precision. Recent enhancement of the data acquisition is enabling rapid acquisition of dispersion curves at such a speed that a curve for 20 angles of incidence is obtained in less than a minute. The ability to acquire curves in very important for the capability to quantitatively map the material properties of laminates at practical time scales.

Figure 1: The JPL's LLW scanner attachment on a C-scan system



JPL NDEAA ACTIVITY II - ROBOTIC NDE

Scanning of aerospace structures NDE using miniature multifunction automated crawler system (MACS) (Yoseph Bar-Cohen, JPL, 818-354-2610, yosi@jpl.nasa.gov, http://ndeaa.jpl.nasa.gov/)

Automated devices that can be attached to an aircraft skin and travel on it can greatly enhance the speed of inspection and minimize human errors. Increasingly, crawling devices are reported as a solution to this need and the use of suction cups has become a leading form of controlled adherence. Several successful mobile portable scanners have emerged in the last several years, including the Automated Non Destructive Inspector and the Autocrawler. In order to meet the need for a compact, more maneuverable crawler, the NDEAA Group of JPL developed recently a small, highly dexterous crawler with a payload to weight ratio of about 10:1. This Multifunction Automated Crawling System (MACS), shown in Figure 1, was designed to perform complex scanning tasks. MACS development team consisted of Dr. Yoseph Bar-Cohen, Dr. Paul Backes and Dr. Benjamin Joffe. The development of MACS was benefited from the ongoing JPL development of miniature planetary rovers, telerobotic technology and NDE techniques. MACS employs ultrasonic motors for mobility and suction cups for surface adherence. It has two legs for linear motion, with one leg serving as the rotation element for turning. MACS was efficiently designed to perform any simultaneous combination of motions, including linear travel as well as rotation around the central axis. While the applications of MACS can include inspection and paint removal, other functions can be easily performed by adequate modifications.

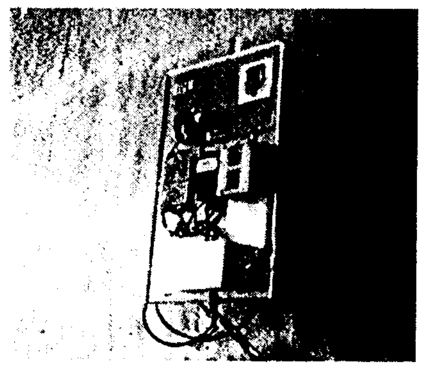


Figure 1: MACS crawling on the C-5 aircraft (patent pending).

Future development of MACS will allow its remote monitoring by centrally located experts that are equipped with know-how, database, analytical tools, CAD drawing, and accept/reject criteria. Controlling MACS remotely via Internet using password will allow authorized users to view and operate it simultaneously. Such capabilities will allow rapid response to inspection needs, particularly in cases of crisis where it is necessary to examine a full flight of a particular aircraft model all over the world. A combination of visual, tap testing, MOI, eddy current and ultrasonics are expected to be the leading NDE capabilities of MACS. Programming the travel of MACS on complex structures will employ JPL telerobotic technology that was developed for the exploration of Mars, including the rover of the Mars Pathfinder mission. MACS is currently using umbilical cords for power, control, and communication as well as pressure tubing to allow ejection and activation of the vacuum suction cups. Further enhancement will be the development of an autonomous MACS to allow operation during aircraft idle time to reduce the need to ground aircraft for inspection. This will require a miniature on-board vacuum pump, power and computing capabilities. Intelligent NDE techniques will be need to allow detection and characterization of flaws and determination of the material properties. Employing local Global Positioning Systems (GPS) will provide absolute coordinates without the need for complex, costly and heavy encoders.

This GPS system will also provide the location of the crawler on the aircraft in relation to the detailed drawings to assist in the determination of flaws dimensions and location. To protect aircraft elements that rise above the surface from being accidentally damaged, a vision system will be used with collision avoidance software. To enhance the inspection capability of the combined systems, a neural network data interpretation can be used.

The personal computers technology offers a model for a low cost rapidly improving crawler, allowing companies with diverse expertise to concentrate on their strength and innovation. As an example, manufacturers of modems can concentrate on producing and improving their product without having to make a complete PC. These companies are enjoying a large customer base from a very wide range of consumers and users. As long as these companies maintain compliance with the evolution of the motherboard architecture, they can continue to improve their products at an incredible rate while reducing the cost. JPL is making efforts to establish MACS as mother-crawler, similar to the idea of the motherboard on the PC, thus functioning as a mobile platform. MACS can provide power, intelligence and communication mainframe, bus and wireless communication, position tracking (local GPS, encoders, etc.), controlled sticksion, actuators and motion control. MACS can be produced with bus architecture (preferably PCI, PCMCIA, or ISA) offering a standard plug-in capability for NDE plug-in boards. Thus, the NDE industry will be able to concentrate on making unique miniature instruments modules that are Plug & Play type for user-friendly operation. The field of robotic NDE is multidisciplinary and no single NDE manufacturing company is expected to poses all the necessary expertise. MACS as a mother-crawler will allow companies from various technology areas to contribute to its modules and the pool of users can be very large including even glass buildings cleaning. Having large pool of manufacturers and users will allow reduction of cost and rapid improvement of the performance. Since the 97 ASNT Fall Conference, Dr. Bar-Cohen started holding sessions on the topic of Robotics and Miniaturized NDT Instruments. The intent of these sessions is to focus the industry and academia attention to this topic of generic mother-crawler and related plug-in modules. Recent government interest in addressing the issue of NDE of corrosion turned the spotlight onto MACS as a potential baseline for robotic multi-sensor platform for rapid scanning of aircraft structures. In future generations of this technology, micro-electronic mechanical systems (MEMS) is expected to lead to extremely small scanning NDE instrumentation that can potentially crawl into engines and other hidden areas and perform inspections and other tasks.